Monitoring LST at canyon scale for urban micro-climate applications: in-situ, simulation and airborne data comparisons

Laure Roupioz, Auline Rodler, Sihem Guernouti, Ahmad Al Bitar, Laurent Poutier, Xavier Briottet, Françoise Nerry, Marjorie Musy

Monitoring LST at canyon scale for urban micro-climate applications: in-situ, simulation and airborne data comparisons

Laure Roupioz
ONERA, DOTA
Université de Toulouse
Toulouse, France
laure.roupioz@onera.fr

Auline Rodler
CEREMA
BPE/LOCIE
Nantes, France
auline.rodler@cerema.fr

Sihem Guernouti
CEREMA
BPE/LOCIE
Nantes, France
sihem.guernouti@cerema.fr

Ahmad Al Bitar
CESBIO
Université de Toulouse
Toulouse, France
albitara@univ-tlse3.fr

Laurent Poutier
ONERA, DOTA
Université de Toulouse
Toulouse, France
laurent.poutier@onera.fr

Xavier Briottet
ONERA, DOTA
Université de Toulouse
Toulouse, France
xavier.briottet@onera.fr

Françoise Nerry
ICUBE
Université de Strasbourg
Illkirch, France
f.nerry@unistra.fr

Marjorie Musy
CEREMA
BPE/LOCIE
Nantes, France
marjorie.musy@cerema.fr

***Abstract*—In a context of more frequent heat waves, urban overheating is a major environmental and public health issue. The Land Surface Temperature (LST) is a key variable to study this phenomenon and its estimation at district or city scale can help to diagnose the thermal behaviour of existing or future infrastructures. This paper compares in-situ sensors, 3D physical models and remote sensing observations to investigate the potential and accuracy of each approach to monitor LST at canyon scale. This comparison is performed based on the datasets acquired during the CAMCATT-AI4GEO experiment led in Toulouse city in June 2021 and a side experiment evaluating iButtons data using KT19 measurements as reference. This work shows that iButtons provide LST within +/- 1.25°C (over white walls) if the sensor is protected from direct sun. They offer a good spatial coverage over a small scene, providing direct LST measurement, but they seem sensitive to dark colour walls and sun exposition. On-ground TIR cameras allow for fine scale monitoring of the spatial and temporal variation of the LST, which provides information on the thermal behaviour of the surfaces over limited portion of the scene. On the other hand, airborne cameras allow to retrieve LST over horizontal surfaces at flight overpass time, which give an instant picture of the LST spatial variability at district or city scale. In both cases, retrieving LST from the thermal infrared images can be challenging. Finally, micro-climat models allow to simulate LST at high spatial and temporal resolutions up to district scale, provided that meteorological data are available and that the scene parametrization is correct. Each approach has advantages and drawbacks in terms of accuracy, spatial and temporal coverage, but they can also benefits from a combined used.**

***Index Terms*—Land surface temperature, in-situ sensors, micro-climate modelling, airborne data**

I. Introduction

Ongoing climate change is exposing urban populations to increasingly frequent extreme weather events, putting the health of the most vulnerable at risk. Supporting urban planning policies to reduce areas of thermal discomfort and the urban heat island phenomenon is therefore as much an environmental as a public health issue. The Land Surface Temperature (LST) is among the key proxy variables to capture heat storage and release from buildings and streets, as well as the impact of urban vegetation, and their effects on micro-scale air temperature. Estimating the LST at district or city scale can help to diagnose the thermal behaviour of existing or future infrastructures. Whether by in-situ sensors, 3D physical models or remote sensing observation, each approach has its advantages and drawbacks in terms of accuracy, spatial and temporal coverage. The CAMCATT-AI4GEO experiment led in Toulouse city in June 2021 combined multiple state-of-the-art methodologies to measure the LST at urban canyon scale. This paper presents the different datasets acquired during this field campaign, compares the measured and simulated LST and finally provides insights on the quality to be expected from direct, model-derived and sensor-derived surface temperature.

II. Material and method

A. Input data and model description

1) Instrumented street canyon: The CAMCATT-AI4GEO experiment conducted during 15 days in June 2021 over Toulouse acquired an urban reference dataset combining airborne acquisitions and ground measurements. In this experiment, a set of student buildings on the ISAE campus was instrumented with different types of sensors to measure the LST of the facades over several days. The objective was to monitor variations on a local scale and, in fine, to validate micro-climatic models. These buildings have a simple geometry, representative of a typical street canyon and were easily accessible for sensors set-up. The scene consists of three

The data used were acquired during the AI4Geo/CAMCATT campaign funded by BPI (AI4GEO) and CNES (APR CNES CAMCATT).

parallel 5-storey buildings, with no balcony. The ground floor is covered with black painted plaster and the upper floors with light grey painted plaster (Fig. 1 (a) and (b)). Several in-situ sensors measured the LST of the outside walls and surrounding surfaces:

- 50 iButtons spread over three buildings and their surroundings, measuring directly the LST by contact during 2 weeks (1 acquisition every 5 minutes with a precision of 0.5 degree). The instrumented facades are surrounded in red in Fig. 1(a).
- a ground based thermal camera (broadband 8-14 µm) set up on the top floor of one of the building, acquiring simultaneously RGB and thermal infrared (TIR) images (Fig. 1 (c) and (d)) every 5 minutes over part of the facade of the central building during 4 days. In this canyon (width/height = 1.3), the radiative contribution of the environment *L(Te)* is close to the target radiance *L(Ts)* and the emissivity (ε) of the surface is high. Based on (1) and considering that $1\text{-}\varepsilon \ll 1$ and $Te \sim Ts$ (evaluated with an infragold plate), the brightness temperature can be assumed as equal to the LST in this specific case.

$$L(Tb) = \varepsilon * L(Ts) + (1 - \varepsilon) * L(Te) \qquad (1)$$

The emissivity and reflectance of the main materials constituting the scene were measured using an ASD field spectrometer and a SOC410T respectively.

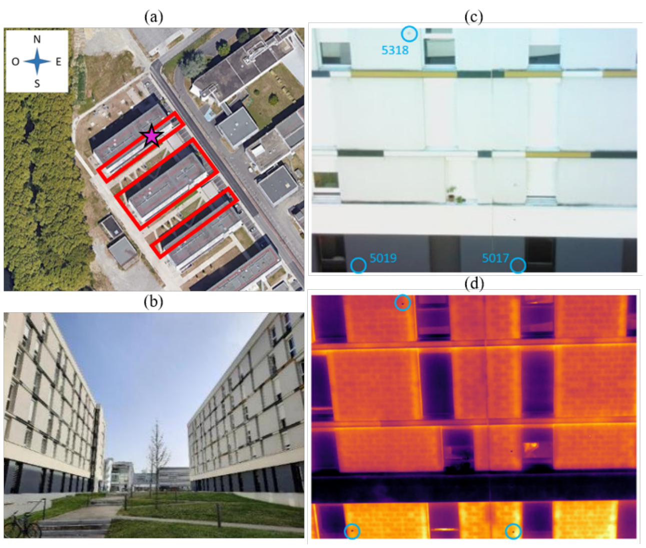

Fig. 1. (a) student buildings with instrumented facades circled in red and on-ground TIR camera location marked by a purple star; (b) zone between two buildings; (c) RGB image acquired by the on-ground camera with iButtons location circled in blue; (d) TIR image acquired by the on-ground camera with iButtons location circled in blue

2) Thermal infrared airborne data: A Telops multispectral camera mounted in an airplane acquired airborne TIR images during the experiment on the 15th of June (11 am UTC). The LST was retrieved from the images by first applying an atmospheric correction using COMANCHE [1] and the data from the atmospheric sounding performed during the flight followed by a TES (Temperature Emissivity Separation) algorithm to generate a LST map of the studied scene.

3) SOLENE-Microclimat: SOLENE-Microclimat is a simulation tool dedicated to urban micro-climate and building thermal behaviour modelling [2]. The simulations are based on a realistic representation of the scene and are forced with local meteorological data. A simple mock-up of the instrumented scene has been generated from the BD TOPO [3] and building measurements. The optical properties attributed to the materials have been derived from the in-situ measurement performed during the campaign and the thermal properties as provided by the building developer when available.

B. Data comparison approach

Before using the data collected by the iButtons, we conducted a side experiment to evaluate their accuracy as their behaviour for outdoor use remains poorly documented. To do so, we compared them with stable and accurate KT19 radiometers (standards in radiometric metrology in remote sensing [4]) for various outdoor configurations. Nine iButtons have been distributed over four zones corresponding to wall sections with different sun expositions. In each zone, two to three iButtons were set up with or without fixation frame and with or without sun protection as listed in Table I and showed in Fig. 3. As for the experiment over the buildings, the iButtons were configured to acquire a value every 5 minutes with a precision of 0.5 degree. Equation (1) was applied to retrieve LST from the KT19 data using an emissivity value very close to unity (known from previous measurement), leading to low impact of the environment radiative contribution. This test run over 3 days.

TABLE I
THE DIFFERENT IBUTTONS SET-UPS FOR THE FOUR ZONES (FS : FRAME+SUN CAP; F : FRAME; S: SUN CAP; N : NOTHING)

Zone	FS	F	S	N
Zone 1 (North)	x	x		x
Zone 2 (Shelter)		x		x
Zone 3 (West)			x	x
Zone 4 (South)	x	x		

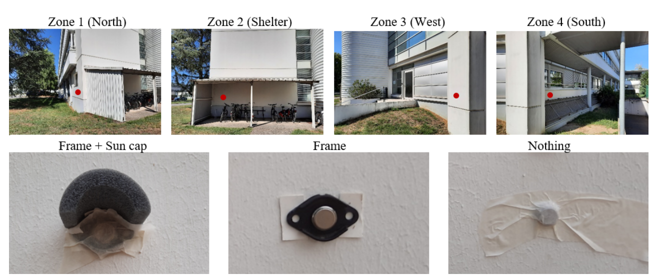

Fig. 2. Top: Location of the four zones (red dot). Bottom : iButtons set-ups

After the inter-comparison of the iButtons and the KT19, the LST simulated by SOLENE-Microclimat is compared with (1) in-situ LST measured by the iButtons and the TIR camera, then (2) with LST retrieved from airborne the TIR acquisition.

III. Results

A. Inter-comparison iButton-KT19

In Fig. 3, the LST acquired by the iButtons and the KT19 is coherent and the use of a fixation frame to set the iButton on the wall does not seem to affect the measurements. However, in case of direct sun light, iButtons tend to overestimate the LST when they are not protected with a sun cap (except in the "Shelter" zone remaining shadowed the whole day).

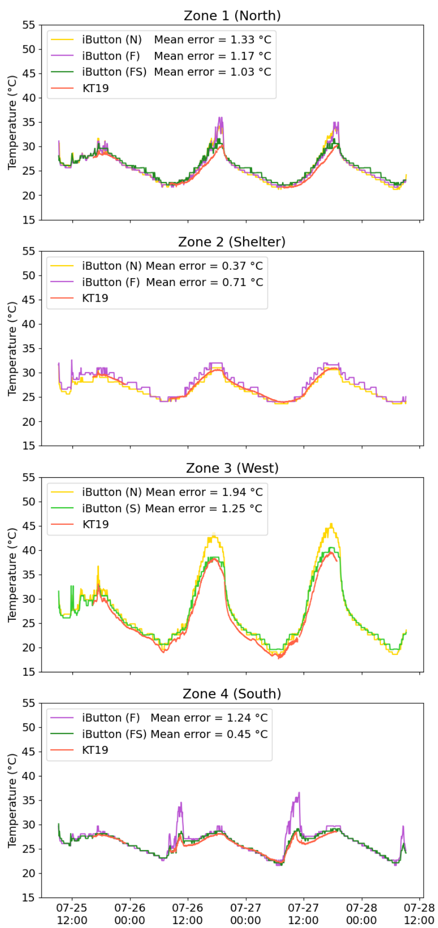

Fig. 3. Comparison of the LST measured by the different iButtons set-ups and the KT19 for the four test zones (FS : Frame+Sun cap; F : Frame; S: Sun cap; N : Nothing)

Excluding iButtons without sun cap, the mean error spread between 0.37 and 1.25°C. Even though KT19 are highly accurate radiometers, part of this error may come from uncertainty on emissivity and environment contribution assumptions. The minimum error is obtained under the shelter while the maximum is obtained over the west facade, which is the warmest zone with the most sun light over the day. Shifts between the LST acquired by the iButtons and the KT19 are sometimes visible, mainly during the wall's warming up phase before or after sun illumination. More tests should be run to further investigate the impact of sun on the iButtons behaviour. Nevertheless, this test showed that the data acquired by the iButtons during the campaign (set-up with a sun cap as shown in Fig. 2) are reliable and can be used, keeping in mind an uncertainty of maximum 1.25°C in this case.

B. Comparison of in-situ and simulated LST

Fig. 4 shows the LST acquired by three iButtons, two at the ground floor (iB5017, iB5019) and one at the third floor (iB5318), and compares them to the LST acquired over the same area by the on-ground TIR camera and simulated by SOLENE-Microclimat. There is generally a good agreement between the iButtons (green line) and TIR camera (red line), with mean errors between 0.41 and 1.02°C, even if large differences appear when the facade receives direct sun light. The largest differences occurs at the ground floor while lowest errors are obtained at the third floor. The difference between iButtons (TIR camera) and simulated LST is larger with mean error values of 3.18, 2.77, 2.77°C (2.91, 2.87, 2.54°C) for iB5017, iB5019 and iB5318 respectively. The simulated LST mostly differ from the iButtons for the coolest and warmest period of the day with more extreme LST provided by SOLENE-Microclimat. The comparison with the TIR images showed differences mostly at nighttime with lower simulated LST while daytime LST are in good agreement. Part of the differences observed between simulated and measured LST may come from the use of a simplified mock-up to represent the scene and the hypothesis made on the parametrization of the material thermal properties. In this work, the simulations are based on thermo-radiative computations without any CFD coupling, which enhance the uncertainty linked to the convective factor.

Even if the comparison with the KT19 showed that suitable LST can be acquired by iButtons equipped with a sun cap, the results in Fig. 4 raise some questions. There is a strong underestimation of the LST measured by the iButtons as compared to the camera or the model during direct sun illumination, mostly for the ground floor and less for the third floor. This may come from the fact that the ground floor is painted in black, leading to higher LST, while the rest of the facade is light grey. This would also explained why this behaviour was not observed during the inter-comparison test, performed only over white walls. In this case, the lower LST measured by the iButtons over black walls could come from a self-shadowing effect.

C. Comparison of airborne and simulated LST

The LST map derived from the airborne image provides the LST of the horizontal surfaces at the flight overpass time (11:43:12 UTC). From it, an averaged LST is computed over the three roofs and over the ground between the buildings. These values are then compared to the LST simulated by SOLENE-Microclimat for the corresponding meshes on the mock-up. For the roofs, the mean simulated LST is 66.47°C while the one derived from the TIR image is 67.66°C. On the ground, the simulated LST is 25.44°C for the lawn and 57.89°C for the pedestrian path. It is not possible to distinguish the lawn from the path on the airborne images on which pixels are mixed. The average LST retrieved over the ground

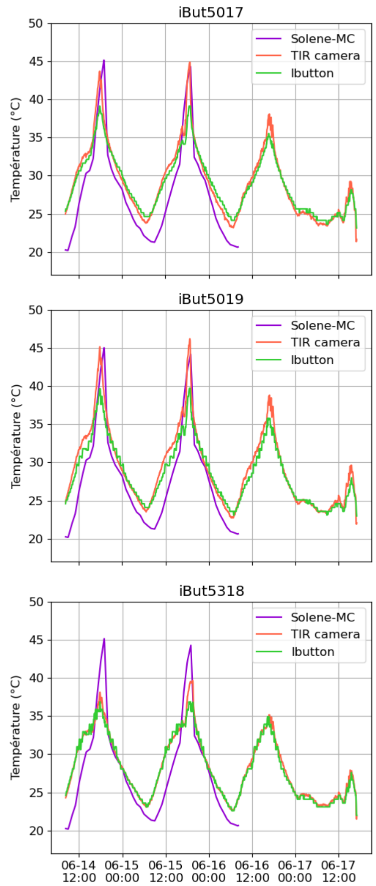

Fig. 4. Comparison of the LST measured by the iButtons, the on-ground TIR camera and LST simulated with SOLENE-Microclimat

between the buildings 47.59°C. This comparison highlight a good agreement between the model and the airborne LST. It is however important to mention that SOLENE-Microclimat was run using a simplified representation of the scene and that the simulated LST can be very sensitive to the definition of material properties, such as the convective heat transfer coefficient which is difficult to parameterize when little or no information is available for the modelled elements. Comparison with a more detailed mock-up are planned and with a whole coupling between thermal, radiative and airflow exchanges.

IV. Conclusions and Perspectives

During the CAMCATT-AI4GEO experiment, three buildings of the ISAE campus, representative of an urban scene, were instrumented with various sensors measuring the LST. The objective of this paper is to compare in-situ sensors, 3D physical models and remote sensing observations to investigate the potential and accuracy of each approach to monitor LST at canyon scale. A side experiment comparing iButtons with KT19 measurements as reference showed that, over relatively smooth and white walls, the iButtons provides reliable LST (maximum +/- 1.25 K) if the sensor is protected from direct sun light. iButtons are well suited for local fine scale studies as they offer a good spatial coverage over a small scene, providing direct LST measurement. However, their use remains limited to small areas and they seem to be sensitive to dark colour wall and sun exposition. The inter-comparison test should be extended to a larger sample of walls (different colours, roughness, . . .) to consolidate these conclusions. The on-ground TIR camera provided a time-series of images with high temporal resolution and showing in detail the spatial heterogeneity of a part of the facade. While this setting is not made to cover large areas, it allows for fine scale monitoring of the spatial and temporal variation of the LST and provides information on the thermal behaviour of the observed surfaces. Nevertheless, it can be challenging to accurately retrieve LST in an environment as closed as a street canyon with complex scene radiative contribution and varying materials emissivities. On the other hand, the airborne camera provided a snapshot of the entire area from which LST could be retrieved. Even if the information is limited to horizontal surfaces and to the time of acquisition, it give an instant picture of the LST variability at district or city scale. Finally, the SOLENE-Microclimat model can simulate LST at metric resolution from canyon to district scale using a mock-up of the scene and forcing meteorological data. In this study, the simplified mock-up used for the simulation led to results consistent with in-situ and airborne measurements, with an underestimation of the LST at night. This modelling approach allows to get LST at high spatial and temporal resolutions up to district scale, provided that meteorological data are available and that the scene parametrization is correct, which may be difficult to set due to lack of information. While each approach has its advantages and drawbacks in terms of accuracy, spatial and temporal coverage, they can also benefits from each other if they are combined such as the used of TIR data to parametrize micro-climatic model [5].

Acknowledgment

The data used were acquired during the AI4Geo/CAMCATT campaign funded by BPI (AI4GEO) and CNES (APR CNES CAMCATT).

References

[1] L. Poutier, C. Miesch, X. Lenot, V. Achard, and Y. Boucher, ”COMANCHE and COCHISE: two reciprocal atmospheric codes for hyperspectral remote sensing,” AVIRIS Earth Science and Applications Workshop Proceedings, 2002.

[2] M. Musy, M. H. Azam, S. Guernouti, B. Morille, and A. Rodler, ”The SOLENE-Microclimat model: potentiality for comfort and energy studies,” in Urban Microclimate Modelling for Comfort and Energy Studies, M. Palme and A. Salvati, Eds Springer, 2021, pp. 265–291.

[3] BDTopo, Institut national de l'information géographique et forestière, https://geoservices.ign.fr/bdtopo.

[4] E. Theocharous, N. P. Fox, I. Barker-Snook, R. Niclòs, V. G. Santos, P. J. Minnett et al, ”The 2016 CEOS Infrared Radiometer Comparison: Part II: Laboratory Comparison of Radiation Thermometers,” J. Atmos. Ocean. Technol., vol. 36(6), pp. 1079-1092, 2019 [10.1175/JTECH-D-18-0032.1]

[5] B. Bouyer, A. Rodler, L. Roupioz, S. Guernouti, M. Musy, and X. Briottet, ”Apport de la télédétection dans la modélisation numérique du microclimat urbain à l'échelle du quartier,” 30ème congrès annuel de la Société Française de Thermique (SFT), May 2022, Valenciennes, France, may 2022 [10.25855/SFT2022-029].